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(54) **LITHOGRAPHIC APPARATUS AND DEVICE MANUFACTURING METHOD**

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See application file for complete search history.

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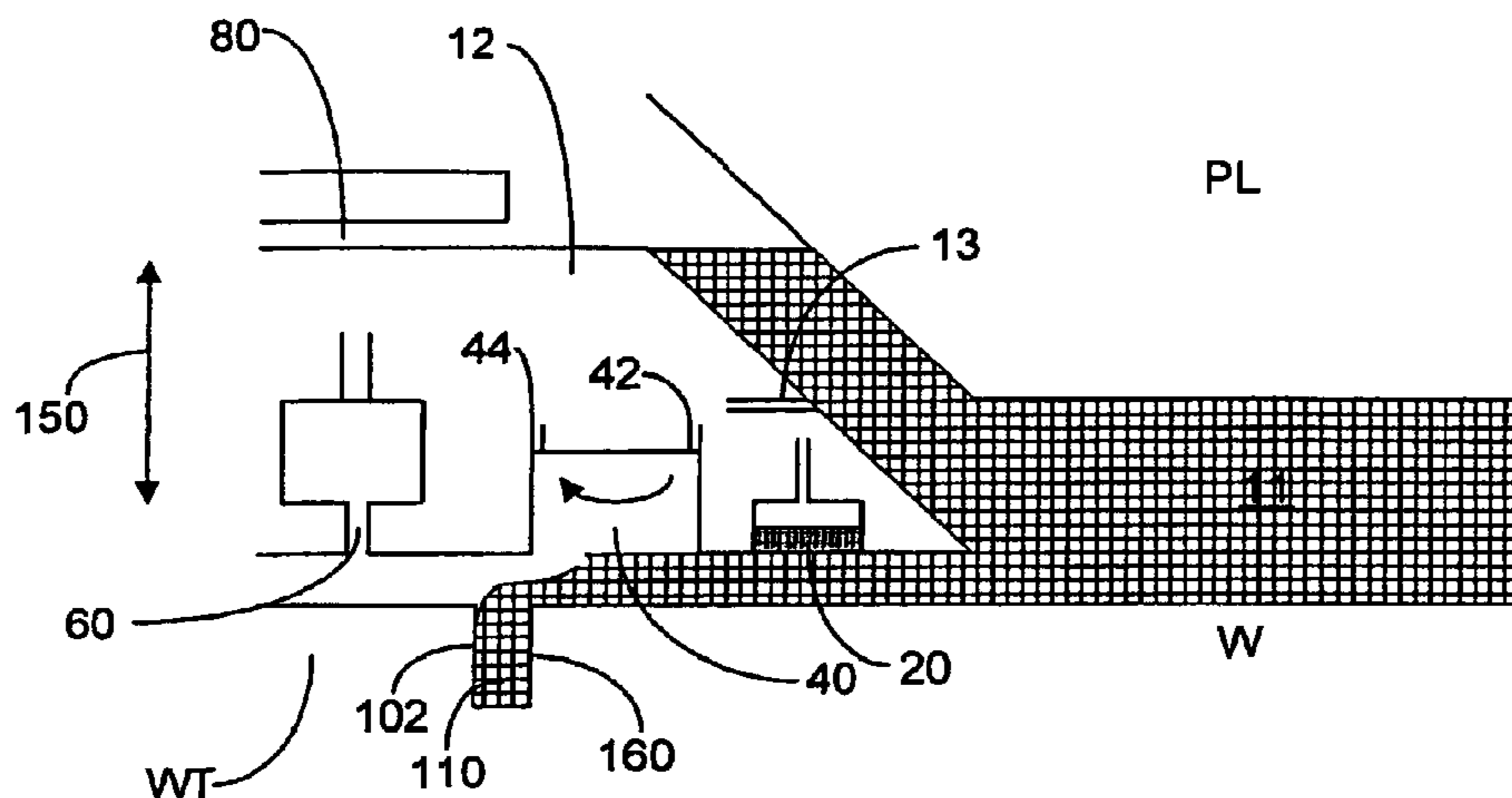
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(57) **ABSTRACT**

A lithographic projection apparatus is disclosed in which measures are taken to prevent or reduce the presence of bubbles in liquid through which the projection beam radiates. This may be done, for example, by ensuring that a gap between a substrate and a substrate table is filled with immersion liquid or by causing a localized flow radially outwardly from the optical axis in the vicinity of the edge of the substrate.

**20 Claims, 4 Drawing Sheets**



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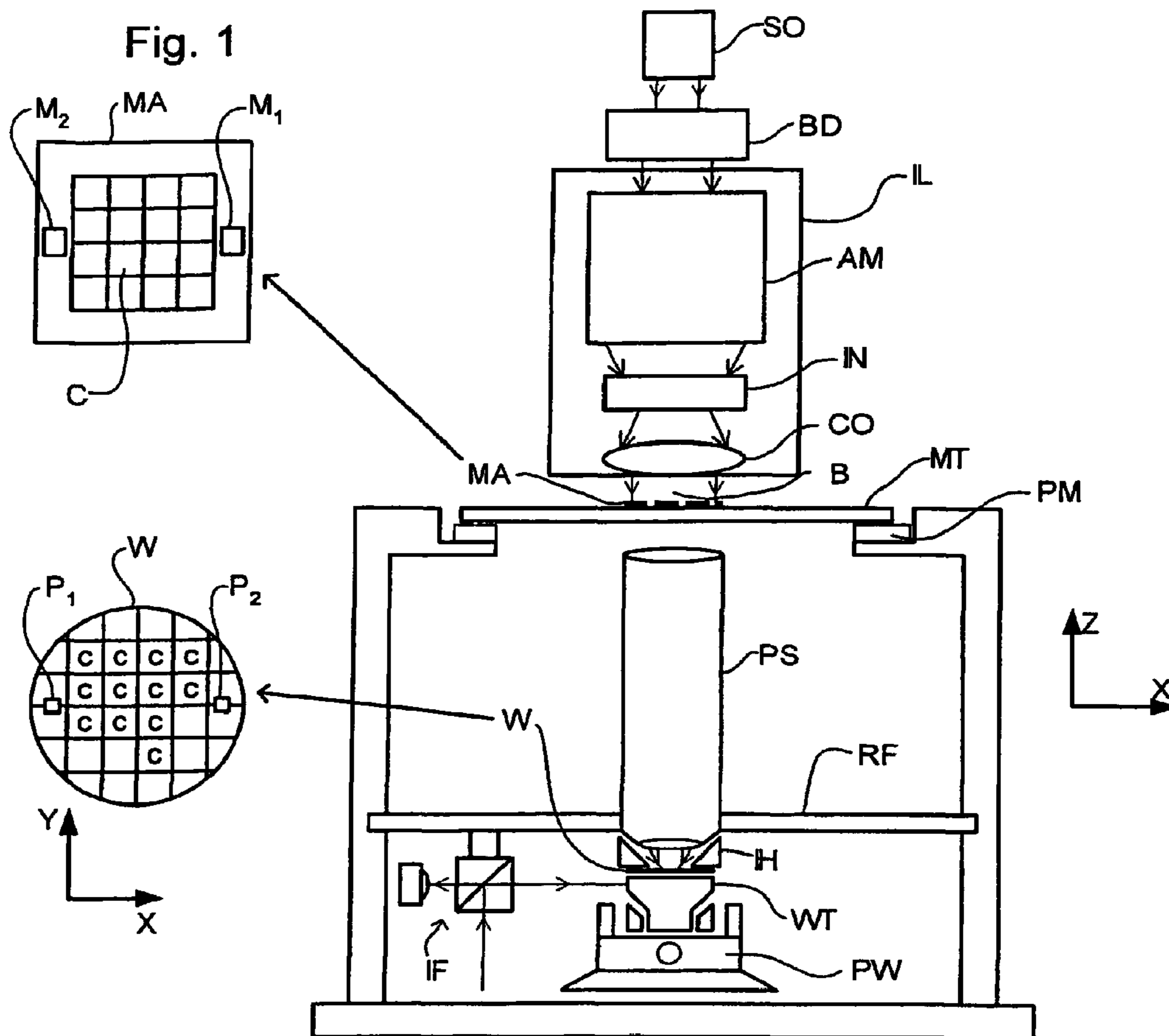


Fig. 2

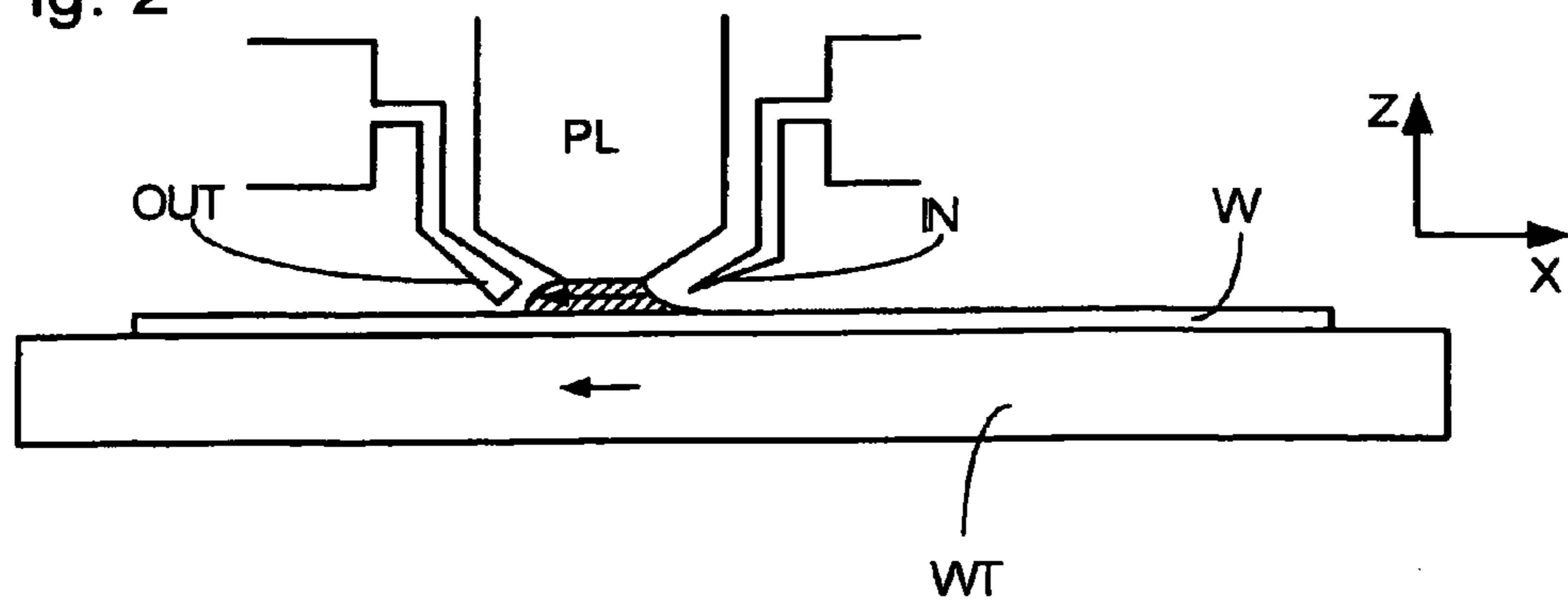


Fig. 3

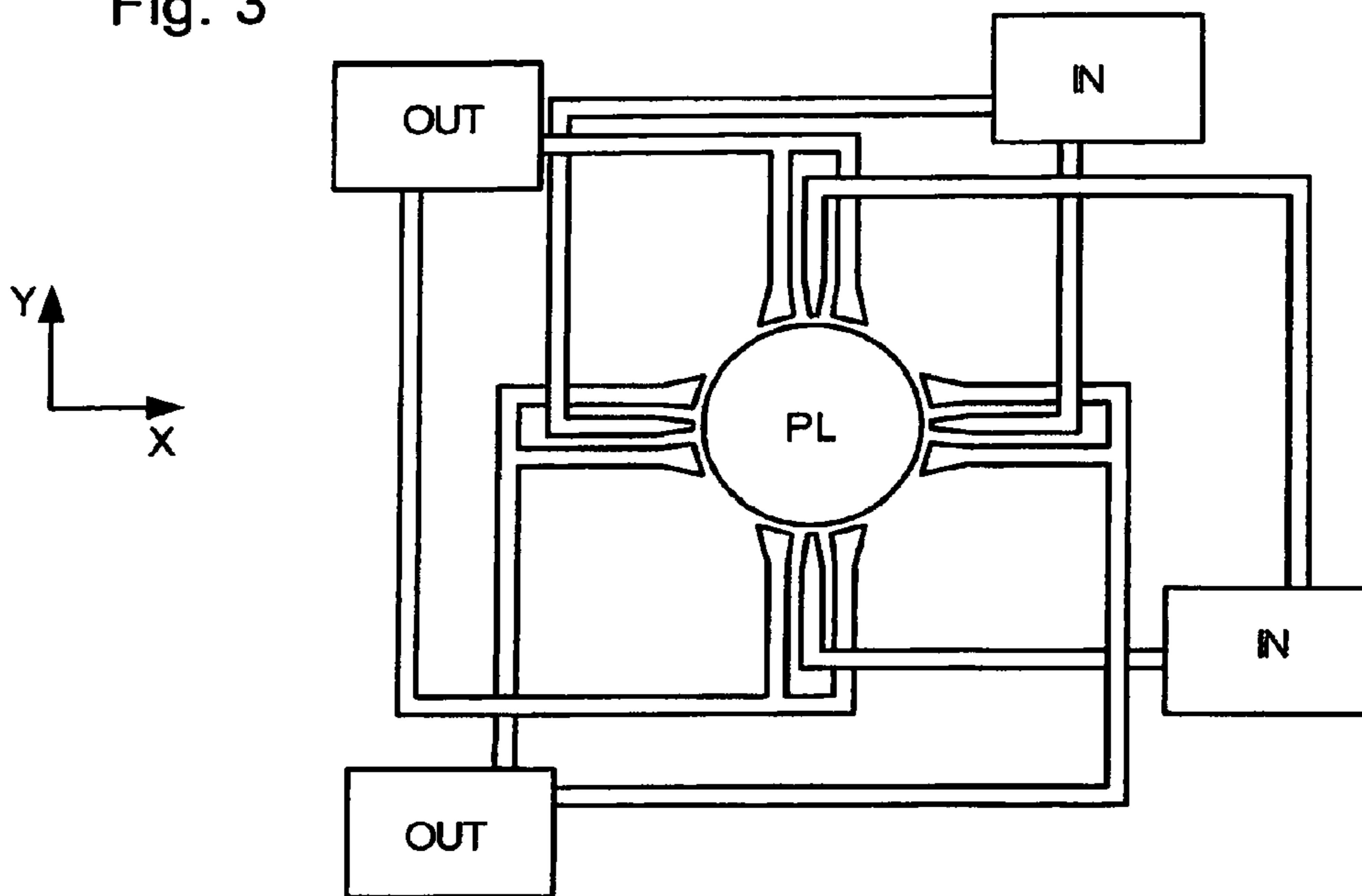


Fig. 4

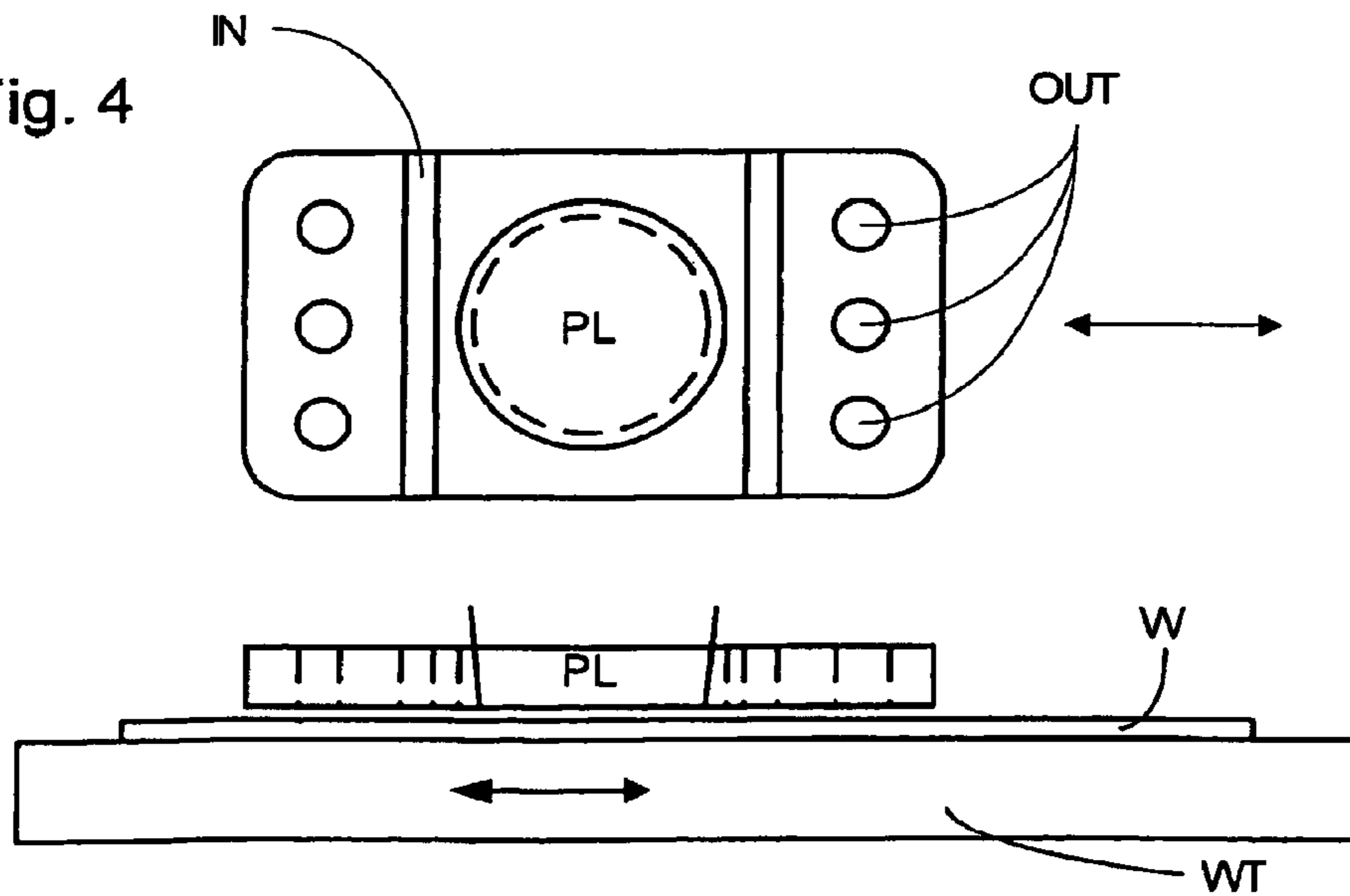


Fig. 5

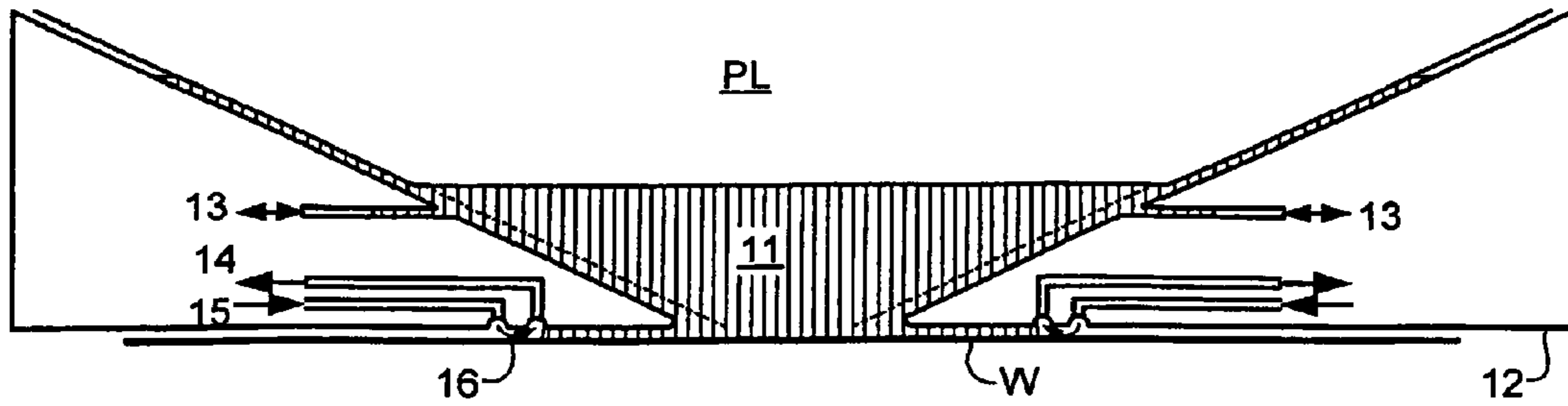


Fig. 6

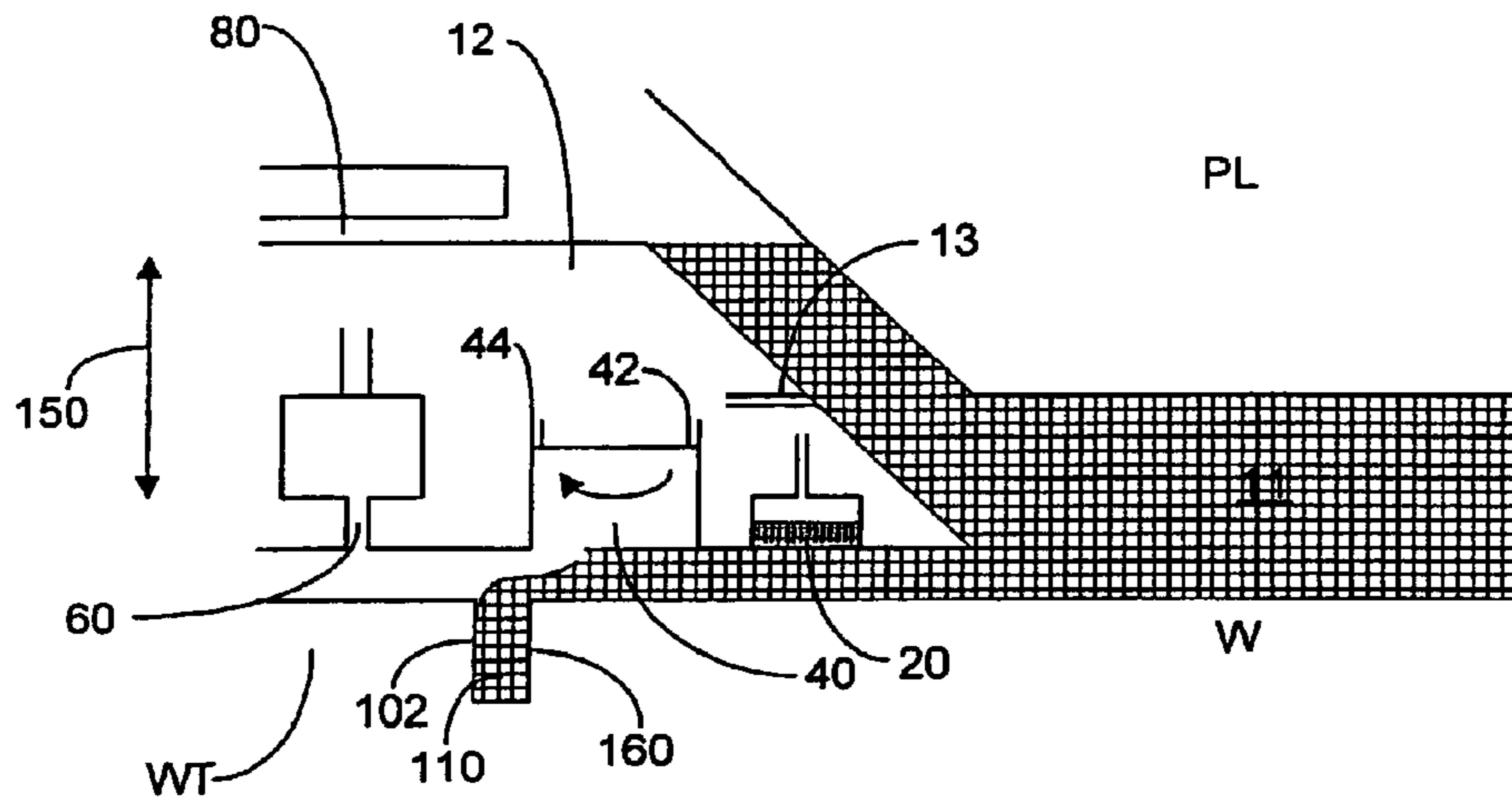
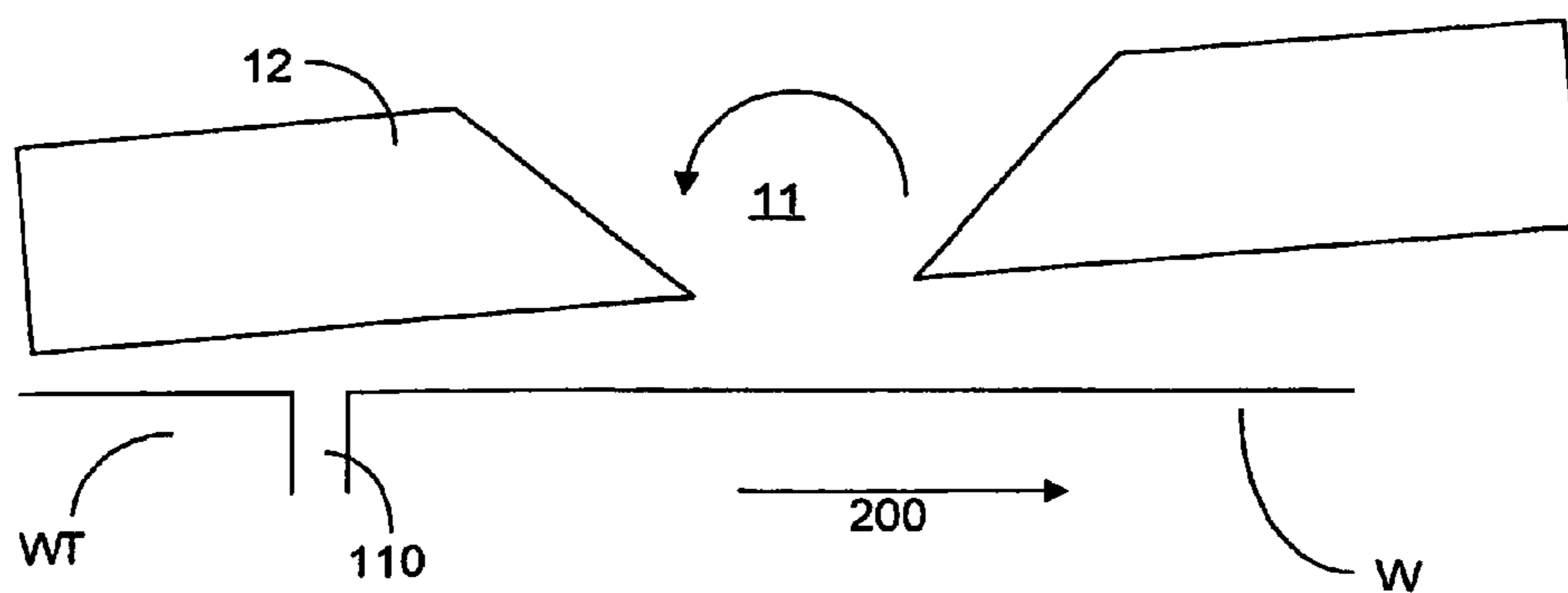


Fig. 7







## LITHOGRAPHIC APPARATUS AND DEVICE MANUFACTURING METHOD

The present application is a continuation of U.S. patent application Ser. No. 12/292,329, filed Nov. 17, 2008, now U.S. Pat. No. 7,929,112, which is a continuation of U.S. patent application Ser. No. 11/167,563, filed Jun. 28, 2005, now U.S. Pat. No. 7,468,779, the entire contents of each of the foregoing applications herein fully incorporated by reference.

### 1. FIELD

The present invention relates to a lithographic apparatus and a method for manufacturing a device.

### 2. BACKGROUND

A lithographic apparatus is a machine that applies a desired pattern onto a substrate, usually onto a target portion of the substrate. A lithographic apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In that instance, a patterning device, which is alternatively referred to as a mask or a reticle, may be used to generate a circuit pattern to be formed on an individual layer of the IC. This pattern can be transferred onto a target portion (e.g. comprising part of, one, or several dies) on a substrate (e.g. a silicon wafer). Transfer of the pattern is typically via imaging onto a layer of radiation-sensitive material (resist) provided on the substrate. In general, a single substrate will contain a network of adjacent target portions that are successively patterned. Known lithographic apparatus include so-called steppers, in which each target portion is irradiated by exposing an entire pattern onto the target portion at one time, and so-called scanners, in which each target portion is irradiated by scanning the pattern through a radiation beam in a given direction (the "scanning"-direction) while synchronously scanning the substrate parallel or anti-parallel to this direction. It is also possible to transfer the pattern from the patterning device to the substrate by imprinting the pattern onto the substrate.

It has been proposed to immerse the substrate in the lithographic projection apparatus in a liquid having a relatively high refractive index, e.g. water, so as to fill a space between the final element of the projection system and the substrate. The point of this is to enable imaging of smaller features since the exposure radiation will have a shorter wavelength in the liquid. (The effect of the liquid may also be regarded as increasing the effective NA of the system and also increasing the depth of focus.) Other immersion liquids have been proposed, including water with solid particles (e.g. quartz) suspended therein.

However, submersing the substrate or substrate and substrate table in a bath of liquid (see, for example, U.S. Pat. No. 4,509,852, hereby incorporated in its entirety by reference) means that there is a large body of liquid that must be accelerated during a scanning exposure. This requires additional or more powerful motors and turbulence in the liquid may lead to undesirable and unpredictable effects.

One of the solutions proposed is for a liquid supply system to provide liquid on only a localized area of the substrate and in between the final element of the projection system and the substrate using a liquid confinement system (the substrate generally has a larger surface area than the final element of the projection system). One way which has been proposed to arrange for this is disclosed in PCT patent application WO 99/49504, hereby incorporated in its entirety by reference. As illustrated in FIGS. 2 and 3, liquid is supplied by at least one

inlet IN onto the substrate, preferably along the direction of movement of the substrate relative to the final element, and is removed by at least one outlet OUT after having passed under the projection system. That is, as the substrate is scanned beneath the element in a  $-X$  direction, liquid is supplied at the  $+X$  side of the element and taken up at the  $-X$  side. FIG. 2 shows the arrangement schematically in which liquid is supplied via inlet IN and is taken up on the other side of the element by outlet OUT which is connected to a low pressure source. In the illustration of FIG. 2 the liquid is supplied along the direction of movement of the substrate relative to the final element, though this does not need to be the case. Various orientations and numbers of in- and out-lets positioned around the final element are possible, one example is illustrated in FIG. 3 in which four sets of an inlet with an outlet on either side are provided in a regular pattern around the final element.

A problem with immersion lithography is the presence of bubbles in the immersion liquid. If the path of the projection beam passes through areas of immersion liquid which contain bubbles this can deleteriously affect the quality of the patterned imaged projected onto the substrate.

### 3. SUMMARY

It is desirable to reduce the presence of bubbles in a part of the immersion liquid through which the projection beam will pass.

According to an aspect of the invention, there is provided a lithographic projection apparatus arranged to project a radiation beam onto a substrate or another object through a liquid which is confined to a space by a barrier member, the apparatus comprising a controller adapted to cause a movement of a part of the barrier member substantially parallel to the direction of the optical axis of the apparatus when the part of the barrier member, the space or both, is positioned above or adjacent an edge of the substrate or the another object.

According to an aspect of the invention, there is provided a lithographic projection apparatus arranged to project a radiation beam onto a substrate or another object through a liquid which is confined to a space by a barrier member, the apparatus comprising a controller adapted, when the barrier member, the space, or both, is positioned above or adjacent an edge of the substrate or another object, to cause or increase a flow of liquid in the proximity of the edge in a direction away from the optical axis of the apparatus.

According to an aspect of the invention, there is provided a lithographic projection apparatus arranged to project a radiation beam onto a substrate or another object through liquid which is confined to a space by a barrier member, wherein a liquid inlet is provided on a bottom surface of the barrier member radially inwardly of an outlet, wherein the inlet is shaped to direct exiting liquid at least partly radially outwardly such that the exiting liquid is effective substantially to prevent bubbles formed in the liquid at a position radially outwardly of the inlet from moving radially inwardly of the inlet.

According to an aspect of the invention, there is provided a lithographic projection apparatus arranged to project a radiation beam onto a substrate through a liquid which is confined to a space by a barrier member, the barrier member comprising a contactless seal configured to extend between the barrier member and a substrate table configured to support the substrate and wherein the seal is configured to completely surround the substrate in a loop.

According to an aspect of the invention, there is provided a device manufacturing method using a lithographic projection



apparatus comprising projecting a patterned beam of radiation through a liquid confined to a space by a barrier member onto a substrate, moving the substrate such that part of the barrier member, the space, or both, is positioned above or adjacent an edge of the substrate, and moving the barrier member in a direction substantially parallel to an optical axis of the apparatus.

According to an aspect of the invention, there is provided a device manufacturing method using a lithographic projection apparatus comprising projecting a patterned beam of radiation through a liquid confined to a space by a barrier member onto a substrate, moving the substrate such that the barrier member, the space, or both, is positioned above or adjacent an edge of the substrate and causing or increasing a flow of liquid in a proximity of the edge in a direction away from an optical axis of the apparatus.

#### 4. BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate corresponding parts, and in which:

FIG. 1 depicts a lithographic apparatus according to an embodiment of the invention;

FIGS. 2 and 3 depict a liquid supply system for use in a lithographic projection apparatus;

FIG. 4 depicts a another liquid supply system for use in a lithographic projection apparatus;

FIG. 5 depicts another liquid supply system;

FIG. 6 depicts schematically an embodiment of the present invention;

FIG. 7 depicts schematically another embodiment of the present invention;

FIG. 8 depicts schematically a liquid confinement system according to an embodiment of the present invention;

FIG. 9 depicts, in plan, a liquid confinement system according to an embodiment of the present invention; and

FIG. 10 depicts a further embodiment of the present invention.

#### 5. DETAILED DESCRIPTION

FIG. 1 schematically depicts a lithographic apparatus according to one embodiment of the invention. The apparatus comprises:

an illumination system (illuminator) IL configured to condition a radiation beam B (e.g. UV radiation or DUV radiation).

a support structure (e.g. a mask table) MT constructed to support a patterning device (e.g. a mask) MA and connected to a first positioner PM configured to accurately position the patterning device in accordance with certain parameters;

a substrate table (e.g. a wafer table) WT constructed to hold a substrate (e.g. a resist-coated wafer) W and connected to a second positioner PW configured to accurately position the substrate in accordance with certain parameters; and

a projection system (e.g. a refractive projection lens system) PS configured to project a pattern imparted to the radiation beam B by patterning device MA onto a target portion C (e.g. comprising one or more dies) of the substrate W.

The illumination system may include various types of optical components, such as refractive, reflective, magnetic, electromagnetic, electrostatic or other types of optical components, or any combination thereof, for directing, shaping, or controlling radiation.

The support structure holds the patterning device in a manner that depends on the orientation of the patterning device, the design of the lithographic apparatus, and other conditions, such as for example whether or not the patterning device is held in a vacuum environment. The support structure can use mechanical, vacuum, electrostatic or other clamping techniques to hold the patterning device. The support structure may be a frame or a table, for example, which may be fixed or movable as required. The support structure may ensure that the patterning device is at a desired position, for example with respect to the projection system. Any use of the terms “reticle” or “mask” herein may be considered synonymous with the more general term “patterning device.”

The term “patterning device” used herein should be broadly interpreted as referring to any device that can be used to impart a radiation beam with a pattern in its cross-section such as to create a pattern in a target portion of the substrate. It should be noted that the pattern imparted to the radiation beam may not exactly correspond to the desired pattern in the target portion of the substrate, for example if the pattern includes phase-shifting features or so called assist features. Generally, the pattern imparted to the radiation beam will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit.

The patterning device may be transmissive or reflective. Examples of patterning devices include masks, programmable mirror arrays, and programmable LCD panels. Masks are well known in lithography, and include mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. An example of a programmable mirror array employs a matrix arrangement of small mirrors, each of which can be individually tilted so as to reflect an incoming radiation beam in different directions. The tilted mirrors impart a pattern in a radiation beam which is reflected by the mirror matrix.

The term “projection system” used herein should be broadly interpreted as encompassing any type of projection system, including refractive, reflective, catadioptric, magnetic, electromagnetic and electrostatic optical systems, or any combination thereof, as appropriate for the exposure radiation being used, or for other factors such as the use of an immersion liquid or the use of a vacuum. Any use of the term “projection lens” herein may be considered as synonymous with the more general term “projection system”.

As here depicted, the apparatus is of a transmissive type (e.g. employing a transmissive mask). Alternatively, the apparatus may be of a reflective type (e.g. employing a programmable mirror array of a type as referred to above, or employing a reflective mask).

The lithographic apparatus may be of a type having two (dual stage) or more substrate tables (and/or two or more mask tables). In such “multiple stage” machines the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposure.

Referring to FIG. 1, the illuminator IL receives a radiation beam from a radiation source SO. The source and the lithographic apparatus may be separate entities, for example when the source is an excimer laser. In such cases, the source is not considered to form part of the lithographic apparatus and the radiation beam is passed from the source SO to the illuminator IL with the aid of a beam delivery system BD comprising, for example, suitable directing mirrors and/or a beam expander. In other cases the source may be an integral part of the lithographic apparatus, for example when the source is a mercury lamp. The source SO and the illuminator IL, together



with the beam delivery system BD if required, may be referred to as a radiation system.

The illuminator IL may comprise an adjuster AD for adjusting the angular intensity distribution of the radiation beam. Generally, at least the outer and/or inner radial extent (commonly referred to as  $\sigma$ -outer and  $\sigma$ -inner, respectively) of the intensity distribution in a pupil plane of the illuminator can be adjusted. In addition, the illuminator IL may comprise various other components, such as an integrator IN and a condenser CO. The illuminator may be used to condition the radiation beam, to have a desired uniformity and intensity distribution in its cross-section.

The radiation beam B is incident on the patterning device (e.g., mask MA), which is held on the support structure (e.g., mask table MT), and is patterned by the patterning device. Having traversed the mask MA, the radiation beam B passes through the projection system PS, which focuses the beam onto a target portion C of the substrate W. With the aid of the second positioner PW and position sensor IF (e.g. an interferometric device, linear encoder or capacitive sensor), the substrate table WT can be moved accurately, e.g. so as to position different target portions C in the path of the radiation beam B. Similarly, the first positioner PM and another position sensor (which is not explicitly depicted in FIG. 1) can be used to accurately position the mask MA with respect to the path of the radiation beam B, e.g. after mechanical retrieval from a mask library, or during a scan. In general, movement of the mask table MT may be realized with the aid of a long-stroke module (coarse positioning) and a short-stroke module (fine positioning), which form part of the first positioner PM. Similarly, movement of the substrate table WT may be realized using a long-stroke module and a short-stroke module, which form part of the second positioner PW. In the case of a stepper (as opposed to a scanner) the mask table MT may be connected to a short-stroke actuator only, or may be fixed. Mask MA and substrate W may be aligned using mask alignment marks M1, M2 and substrate alignment marks P1, P2. Although the substrate alignment marks as illustrated occupy dedicated target portions, they may be located in spaces between target portions (these are known as scribe-lane alignment marks). Similarly, in situations in which more than one die is provided on the mask MA, the mask alignment marks may be located between the dies.

The depicted apparatus could be used in at least one of the following modes:

1. In step mode, the mask table MT and the substrate table WT are kept essentially stationary, while an entire pattern imparted to the radiation beam is projected onto a target portion C at one time (i.e. a single static exposure). The substrate table WT is then shifted in the X and/or Y direction so that a different target portion C can be exposed. In step mode, the maximum size of the exposure field limits the size of the target portion C imaged in a single static exposure.

2. In scan mode, the mask table MT and the substrate table WT are scanned synchronously while a pattern imparted to the radiation beam is projected onto a target portion C (i.e. a single dynamic exposure). The velocity and direction of the substrate table WT relative to the mask table MT may be determined by the (de-)magnification and image reversal characteristics of the projection system PS. In scan mode, the maximum size of the exposure field limits the width (in the non-scanning direction) of the target portion in a single dynamic exposure, whereas the length of the scanning motion determines the height (in the scanning direction) of the target portion.

3. In another mode, the mask table MT is kept essentially stationary holding a programmable patterning device, and the

substrate table WT is moved or scanned while a pattern imparted to the radiation beam is projected onto a target portion C. In this mode, generally a pulsed radiation source is employed and the programmable patterning device is updated as required after each movement of the substrate table WT or in between successive radiation pulses during a scan. This mode of operation can be readily applied to maskless lithography that utilizes programmable patterning device, such as a programmable mirror array of a type as referred to above.

Combinations and/or variations on the above described modes of use or entirely different modes of use may also be employed.

A further immersion lithography solution with a localized liquid supply system is shown in FIG. 4. Liquid is supplied by two groove inlets IN on either side of the projection system PL and is removed by a plurality of discrete outlets OUT arranged radially outwardly of the inlets IN. The inlets IN and OUT can be arranged in a plate with a hole in its center and through which the projection beam is projected. Liquid is supplied by one groove inlet IN on one side of the projection system PL and removed by a plurality of discrete outlets OUT on the other side of the projection system PL, causing a flow of a thin film of liquid between the projection system PL and the substrate W. The choice of which combination of inlet IN and outlets OUT to use can depend on the direction of movement of the substrate W (the other combination of inlet IN and outlets OUT being inactive).

Another solution which has been proposed is to provide the liquid supply system with a barrier member which extends along at least a part of a boundary of the space between the final element of the projection system and the substrate table. The barrier member is substantially stationary relative to the projection system in the XY plane though there may be some relative movement in the Z direction (in the direction of the optical axis). In an embodiment, a seal is formed between the barrier member and the surface of the substrate. The seal may be a contactless seal such as a gas seal. Such a system is disclosed in United States patent application publication no. US 2004-0207824 and European patent application publication no. EP 1420298, each hereby incorporated in its entirety by reference, and illustrated in FIG. 5.

As shown in FIG. 5, an immersion liquid is confined to a space 11 between the final element of the projection system PL and the substrate W. The liquid confinement system comprises a barrier member 12 which provides an inner surface which defines the space 11. Immersion liquid is provided to the space 11 through inlets/outlets 13 and a contactless seal is formed between a bottom surface of the barrier member 12 and the substrate W using a flow of gas 16 between a gas inlet 15 and a gas/immersion liquid outlet 14.

A problem in immersion lithography is the presence of bubbles in the immersion liquid in the space 11. The presence of bubbles in this space can have a detrimental effect on the imaging quality of the apparatus. A particularly problematic source of bubbles may be present at the edge of the substrate W. When an edge of the substrate is to be imaged, the substrate is moved to a position such that one of its edges is present below the space 11. Measures may be taken to make the gap 110 between the edge of the substrate W and the substrate table WT on which the substrate is positioned as small as possible and to ensure that the top surface of the substrate W and the substrate table WT are co-planar. However, in order to account for tolerances in both the size of the substrate W and to ease handling of the substrate W, a small gap 110 will almost always exist. The difficulty with this gap is that gas (e.g., air) can be entrapped in the gap and, when the substrate W edge moves under the space 11 which contains



immersion liquid, bubbles can be released into the immersion liquid from the gap **110** by interaction with the meniscus and/or by free floating bubbles out of the gap. This problem may also exist for other components on the substrate table which may need to be imaged through the immersion liquid such as a sensor, including, for example, a transmission image sensor. An embodiment of the present invention will be described in relation to the substrate W edge, but it is equally applicable to any other object over whose edge the space **11** or barrier member **12** passes e.g. a gutter around a closing plate (which is used to contain immersion liquid under the projection system during, for example, substrate swap).

The problem of the edge of the substrate W being a bubbles source is particularly relevant to a liquid confinement system in which the space **11** filled with immersion liquid is, in plan, smaller in area than the substrate W. Such a liquid confinement system is illustrated in all of the Figures and supplies immersion liquid to only a localized area of the substrate.

In FIG. **6** one way of reducing or minimizing the effect of bubbles is illustrated on a barrier member **12** of the sort described in U.S. patent application Ser. No. 11/098,615, filed 5 Apr. 2005, which is hereby incorporated in its entirety. This type of barrier member **12** comprises, from its radially inner most edge on its bottom surface, a liquid removal device **20** such as the one disclosed in U.S. patent application Ser. No. 10/921,348, filed 19 Aug. 2004, which is hereby incorporated in its entirety. Radially outwardly of the liquid removal device **20** is provided a recess **40** which is connected through an inlet **42** to the atmosphere and via an outlet **44** to a low pressure source such that a flow of gas from inlet **42** to outlet **44** (radially outwardly) is developed. Radially outwardly of recess **40** is a gas knife **60**. The arrangement of these three items on the bottom surface of the barrier member **12** is described in detail in U.S. patent application 60/643,626, filed 14 Jan. 2005, which is hereby incorporated in its entirety. Immersion liquid is provided to the space through an inlet **13** in an inner side wall of the barrier member **12** which defines the space. An outlet **80** is provided towards the top of the inner surface of the barrier member **12** and immersion liquid can flow from the space out through the outlet **80** when the level of liquid in the space is greater than a desired height. The inlet **13** and outlet **80** are illustrated schematically only. Any type of inlet/outlet can be used including those illustrated in FIGS. **2-4** but a desired version is illustrated in U.S. patent application 60/643,626.

As will be clear, during imaging of the substrate W or another object, such as a sensor, with the projection beam PB, the substrate table WT is moved relative to the projection system PL. The barrier member **12** is held generally stationary to the projection system PL though may be actuated in the Z direction and tilted around the  $R_x$  and  $R_y$  axes in order to maintain a substantially constant distance to the top surface of the substrate W, substrate table WT or sensor. It will be appreciated that the substrate table WT will shift the substrate W in the X and Y directions so that all areas can be imaged and will also, during imaging, move the substrate W up and down in the Z direction and tilt it in the  $R_x$  and  $R_y$  axes to account for local topographic variations in the top surface of the substrate W. A controller controls the position of the barrier member **12** in order to substantially maintain constant the height of the barrier member **12** relative to the substrate W. Such an arrangement is disclosed European patent application EP-A-1,477,856 and U.S. patent application Ser. No. 10/844,575, filed May 13, 2004, both of which are hereby incorporated in their entirety. In an embodiment of the present invention, this controller is adapted to apply further movements to the barrier member **12** in order to reduce the chances of bubbles emerg-

ing from the gap **110** between an edge **100** of the substrate W and an edge **102** of the substrate table WT. The same or a different controller can control the supply of immersion liquid and/or gas to the barrier member **12**.

The first possible type of such movement is illustrated in FIG. **6** in which arrow **150** shows that the controller causes additional movement of the barrier member **12** in the Z direction when the barrier member **12** or the space **11** is above or adjacent to the gap **110** or when the gap **110** is being approached.

In an embodiment, the barrier member **12** is lowered towards the substrate W further than it would normally be such that immersion liquid is squeezed into the gap **110**. This movement may be followed by an upward motion to return the barrier member **12** to its original position or to move it to a position above where it would normally be. This cycle may be repeated so that the barrier member **12** oscillates in the Z direction as illustrated by arrow **150** but usually this is not necessary and one cycle each time the barrier member **12** crosses the edge is normally adequate i.e. it oscillates at the same frequency as the die scan frequency which is about 1.5 Hz and between 1 and 8 times per row depending on the die layout and the row scan frequency is about 0.1 to 0.5 Hz. The oscillation is not necessarily periodic when it is synchronized with the substrate table WT motion. Typically the barrier member **12** is positioned about 100  $\mu\text{m}$  above the substrate W. This is the so called "fly height" and this can be in the range of perhaps 75  $\mu\text{m}$  to 1 mm. The lowering motion of the barrier member **12** is, in an embodiment, from the normal fly height to within about 30 to 50  $\mu\text{m}$  of the substrate. The speed of the cycle is related to the scan speed of the substrate W and the width of the gap **110**. Typically the cycle period of the barrier member in the Z direction is about 0.5 s with a substrate W scan speed of 500 mm/s. Typical ranges for the cycle period is 0.1 and 50 ms.

In the above description it is assumed that the barrier member **12** moves up and down in the Z direction uniformly (i.e. without any rotation around the  $R_x$  and  $R_y$  directions). However, this is not necessarily the case and movement of the barrier member **12** in the Z direction can be arranged such that the maximum movement occurs to the part of the barrier member **12** in the position above or adjacent the gap **110** and that those parts distant from the gap only move slightly i.e. a tilt of the barrier member **12** is induced.

In an embodiment, only an upwards movement of the barrier member **12** in the Z direction is added to any other movement required for the normal functioning of a barrier member **12** so that the barrier member **12** moves away from the substrate or substrate table or sensor and this acts to stabilize a meniscus **160** of the immersion liquid below the barrier member **12** at the edge of the space **11** and which is influenced by the gas flow in the recess **40**. This may be accomplished by uniform movement or by tilting as described above. The upward movement reduces the speed of gas from the gas knife thereby reducing disturbances on the meniscus and also reduces viscous forces on the meniscus so that the gap can more easily be filled by capillary action.

FIG. **7** illustrates an embodiment in which, as a gap **110** between a substrate W or another object and the substrate table WT approaches the space **11** (i.e. the substrate table WT moves in direction **200** illustrated in FIG. **7**), the barrier member **12** is tilted towards the approaching gap **110** so that immersion liquid is squeezed into the gap **110** by the horizontal pressure gradient generated in the immersion liquid in the space so that the gap **110** is filled with immersion liquid under a higher pressure than would be present if the barrier member **12** remained unfilled. This tilt of the barrier member



12 can be maintained whilst the gap 110 is in the vicinity or under the space 11 or whilst the gap is adjacent or below the barrier member 12 or the tilt can be removed before the gap 110 is moved away from that position. The tilt can be applied at one time or can be increased gradually as the gap 110 approaches the barrier member 12 or space 11.

A further or alternative way in which the deterioration of the imaged quality can be reduced is to ensure that when the barrier member 12 and/or the space 11 is positioned above or adjacent a gap 110, a flow of immersion liquid in the proximity of the gap 110 in a direction away from the optical axis of the apparatus is encouraged i.e. a flow is generated or an existing flow is increased. The flow of immersion liquid or increase in flow of immersion liquid away from the optical axis of the projection system ensures that the bubbles which are formed at the gap 110 are prevented or reduced from entering the space 11 by the flow. A separate controller may be used for this task or the same controller as that used for normally controlling the direction of flow of immersion liquid can be used. The flow can be generated indirectly by varying the pressure in the immersion liquid.

U.S. patent application Ser. No. 11/098,615, filed 5 Apr. 2005 discloses how flow of immersion liquid across the space 11 can be promoted, particularly in relation to providing an input only around a fraction of the inner surface of the barrier member 12 and an output also around only a fraction of the barrier member 12 which fraction is positioned on the other side of the space 11 to the fraction of the inlet. This system may be used in an embodiment of the present invention.

In the embodiment of FIG. 8, an extra inlet 300 is provided on the bottom surface of the barrier member 12 which is positioned between the liquid removal device 20 and the recess 40. The inlet 300 is angled and/or shaped to direct immersion liquid exiting the inlet at least partially radially outwardly, such that the exiting immersion liquid is effective substantially to prevent or reduce bubbles formed in the immersion liquid at a position radially outwardly of the inlet (e.g. at the gap 110) from moving radially inwardly of the inlet towards the middle of the space 11 through which the projection beam radiates. In an embodiment, the inlet 300 is provided in a loop around the space 11 but may be only provided around a portion of the barrier member 12, for instance around a fraction of the periphery similar to the fraction of the periphery around which the outlet is provided in the barrier member of U.S. patent application Ser. No. 11/098,615.

A controller can also be used to provide the desired direction of flow by varying the rate of flow of immersion liquid through inlets/outlets around the periphery of the barrier member. This can be achieved by, for example, providing the liquid removal device 20 as individual discrete segments around the periphery of the barrier member 12 which are individually controllable. This is illustrated in FIG. 9. In a similar way, the inlet 13, recess 40 and gas knife 60 can also be provided in segments around the periphery of the barrier member 12 such that by controlling the various pressures and/or flow rates of immersion liquid and/or gas through those inlets and outlets the direction of flow of immersion liquid can be controlled to achieve the desired liquid flow as described above. The desired increase in flow is achievable by increasing the extraction in the region above the gap 110 for example.

If the barrier member is of the type where the direction of flow of immersion liquid in the space is substantially constant relative to the barrier member (e.g. the one disclosed in U.S. patent application Ser. No. 11/098,615 or U.S. patent application 60/643,608, filed 14 Jan. 2005), it is possible to rotate

the barrier member around the optical axis in a plane substantially perpendicular to the optical axis to ensure that the flow of immersion liquid in the proximity of the gap 110 is always radially outwardly i.e. in a direction away from the optical axis of the apparatus. This is illustrated in FIGS. 10a and 10b where it can be seen that at different positions on the substrate W close to the edge of the substrate W the barrier member 12 is rotated to ensure that direction 400 of flow of immersion liquid is radially outward.

In an embodiment, it may be advantageous to reduce or turn off the flow of gas through the gas knife 60 when the gas knife is positioned above the gap 110. This is because the high pressure of exiting gas can blow immersion liquid in the gap 110 out thereby inducing the formation of bubbles in the immersion liquid. Furthermore, reducing the velocity of gas exiting the gas knife is effective not to hinder filling of the gap 110 with immersion liquid under capillary forces. It is advantageous to not completely disrupt the flow of gas through the gas knife 60 but merely to reduce it. One way of conveniently providing a way of reducing the flow of gas through the gas knife is to form the final constriction through which gas exits the gas knife with the vertical walls of concentric rings or members which are moveable relative to each other. In this way the width of the gap can be varied and thereby the exiting velocity of gas without reducing the velocity to zero.

In a further or alternative embodiment, a barrier member 12 is provided which completely surrounds the whole of the substrate W. Thus, a seal is formed between the barrier member 12 and the substrate table WT during imaging of the substrate W and the substrate W is surrounded in a complete loop by the barrier member 12. In this embodiment the barrier member 12 is moveable in the XY plane relative to the projection system PL to the extent that is required for imaging the upper surface of the substrate W. In this embodiment relative movement of immersion liquid to the gap 110 does not occur to a great extent such that the formation of bubbles is avoided. The barrier member 12 can also be moved over the substrate W when, for example, a sensor needs to be imaged.

All of the above embodiments may be used in any combination or individually.

In European patent application publication no. EP 1420300 and United States patent application publication no. US 2004-0136494, each hereby incorporated in their entirety by reference, the idea of a twin or dual stage immersion lithography apparatus is disclosed. Such an apparatus is provided with two tables for supporting a substrate. Leveling measurements are carried out with a table at a first position, without immersion liquid, and exposure is carried out with a table at a second position, where immersion liquid is present. Alternatively, the apparatus has only one table.

Although specific reference may be made in this text to the use of lithographic apparatus in the manufacture of ICs, it should be understood that the lithographic apparatus described herein may have other applications, such as the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, flat-panel displays, liquid-crystal displays (LCDs), thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "wafer" or "die" herein may be considered as synonymous with the more general terms "substrate" or "target portion", respectively. The substrate referred to herein may be processed, before or after exposure, in for example a track (a tool that typically applies a layer of resist to a substrate and develops the exposed resist), a metrology tool and/or an inspection tool. Where applicable, the disclosure herein may be applied to such and other substrate processing tools. Further, the



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substrate may be processed more than once, for example in order to create a multi-layer IC, so that the term substrate used herein may also refer to a substrate that already contains multiple processed layers.

The terms “radiation” and “beam” used herein encompass all types of electromagnetic radiation, including ultraviolet (UV) radiation (e.g. having a wavelength of or about 365, 248, 193, 157 or 126 nm).

The term “lens”, where the context allows, may refer to any one or combination of various types of optical components, including refractive and reflective optical components.

While specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. For example, the invention may take the form of a computer program containing one or more sequences of machine-readable instructions describing a method as disclosed above, or a data storage medium (e.g. semiconductor memory, magnetic or optical disk) having such a computer program stored therein.

One or more embodiments of the invention may be applied to any immersion lithography apparatus, in particular, but not exclusively, those types mentioned above and whether the immersion liquid is provided in the form of a bath or only on a localized surface area of the substrate. A liquid supply system as contemplated herein should be broadly construed. In certain embodiments, it may be a mechanism or combination of structures that provides a liquid to a space between the projection system and the substrate and/or substrate table. It may comprise a combination of one or more structures, one or more liquid inlets, one or more gas inlets, one or more gas outlets, and/or one or more liquid outlets that provide liquid to the space. In an embodiment, a surface of the space may be a portion of the substrate and/or substrate table, or a surface of the space may completely cover a surface of the substrate and/or substrate table, or the space may envelop the substrate and/or substrate table. The liquid supply system may optionally further include one or more elements to control the position, quantity, quality, shape, flow rate or any other features of the liquid.

The descriptions above are intended to be illustrative, not limiting. Thus, it will be apparent to one skilled in the art that modifications may be made to the invention as described without departing from the scope of the claims set out below.

The invention claimed is:

**1.** An immersion lithographic projection apparatus, comprising:

- a movable table configured to support an object;
- a projection system configured to direct a patterned beam of radiation onto a substrate;
- a liquid supply system configured to supply liquid to a space between the projection system and the table, the liquid supply system comprising a barrier member to at least partly confine the liquid in the space, a part of the barrier member comprising an outlet configured to remove liquid; and
- a controller configured to cause variation in a distance between at least the part of the barrier member and the table or to further vary a distance between at least the part of the barrier member and the table, due to at least the part of the barrier member coming to be positioned above or adjacent an edge of the object.

**2.** The apparatus of claim 1, wherein the varying is additional to any variation in distance between the barrier member and the table made in response to other factors.

**3.** The apparatus of claim 1, wherein the varying comprises change of an angle of a lower surface of the barrier member

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relative to a top surface of the object during motion of the table relative to the barrier member.

**4.** The apparatus of claim 1, wherein the varying comprises a tilt of at least the part of the barrier member such that the part is closer to the plane of a top surface of the object than other parts of the barrier member.

**5.** The apparatus of claim 4, wherein the tilt occurs before at least the part of the barrier member is above the edge of the object.

**6.** The apparatus of claim 4, wherein the tilt remains until at least the part of the barrier member is no longer positioned above or adjacent the edge of the object.

**7.** The apparatus of claim 4, wherein the tilt increases as the edge of the object approaches, moves under, or both, at least the part of the barrier member.

**8.** The apparatus of claim 1, wherein the varying increases the distance between at least the part of the barrier member and the table.

**9.** A device manufacturing method, comprising:  
 projecting a patterned beam of radiation, through a liquid at least partly confined to a space by a barrier member, onto a substrate, a part of the barrier member comprising an outlet configured to remove liquid;  
 moving a table supporting an object such that at least the part of the barrier member is positioned above or adjacent an edge of the object; and  
 causing varying in a distance between at least the part of the barrier member and the table or further varying a distance between at least the part of the barrier member and the table, due to at least the part of the barrier member coming to be positioned above or adjacent the edge of the object.

**10.** The method of claim 9, wherein the varying is additional to any variation in distance between the barrier member and the table made in response to other factors.

**11.** The method of claim 9, wherein the varying comprises changing an angle of a lower surface of the barrier member relative to a top surface of the object during motion of the table relative to the barrier member.

**12.** The method of claim 9, wherein the varying comprises tilting at least the part of the barrier member such that the part is closer to the plane of a top surface of the object than other parts of the barrier member.

**13.** The method of claim 12, wherein the tilting occurs before at least the part of the barrier member is above the edge of the object.

**14.** The method of claim 12, wherein the tilt remains until at least the part of the barrier member is no longer positioned above or adjacent the edge of the object.

**15.** The method of claim 12, wherein the tilting increases as the edge of the object approaches, moves under, or both, at least the part of the barrier member.

**16.** The method of claim 9, wherein the varying increases the distance between at least the part of the barrier member and the table.

**17.** A method of operating a lithographic apparatus, the method comprising:  
 moving a table supporting an object relative to a projection system of the lithographic apparatus, the projection system configured to project a patterned beam of radiation through a liquid confined by a barrier member onto a substrate, a lower surface of the barrier member comprising an outlet configured to remove liquid; and  
 causing varying in an angle of the lower surface of the barrier member relative to a top surface of the object or further varying an angle of the lower surface of the barrier member relative to a top surface of the object, due

to at least part of the lower surface of the barrier member coming to be positioned above or adjacent the edge of the object.

18. The method of claim 17, wherein the varying decreases a distance between at least the part of the barrier member and the object. 5

19. The method of claim 17, wherein the varying increases a distance between at least the part of the barrier member and the object.

20. The method of claim 17, wherein the varying occurs before at least the part of the barrier member is above the edge of the object. 10

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UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 8,687,168 B2  
APPLICATION NO. : 13/083966  
DATED : April 1, 2014  
INVENTOR(S) : Roelof Frederik De Graaf et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page

On Page 2, Item (56) References Cited - U.S. Patent Documents, Column 1, Line 65  
replace "2006/0038969 A1 2/2006 Baselmans et al."  
with --2006/0038968 A1 2/2006 Kemper et al.--.

On Page 3, Item (56) References Cited - Other Publications, Column 2, Line 14  
replace "nonparaxial  $\Lambda$ /NA scaling."  
with --nonparaxial  $\lambda$ /NA scaling.--.

Signed and Sealed this  
Twelfth Day of August, 2014



Michelle K. Lee  
*Deputy Director of the United States Patent and Trademark Office*